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Title: DYNAMICS AND VARIABILITY OF THE PLASMASPHERE OBSERVED FROM SYNCHRONOUS ORBIT

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Dynamics and Variability of the Plasmasphere Observed from Synchronous Orbit

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Abstract. The behavior of the cold ions in the outer plasmasphere is studied using data obtained with the magnetospheric plasma analyzers from multiple geosynchronous satellites. Dense (10-100 cm^{-3}), cold ($\approx$1 eV) regions of plasma are often observed at geosynchronous orbit; in this study we refer to these as plasmaspheric intervals. The duration, local time of observation, density variability, and temperature behavior within these regions often depend in a systematic way on geomagnetic and substorm activity. With increasing geomagnetic activity (as indicated by Kp) the plasmaspheric regions are generally observed over shorter durations and at earlier local times. With increasing substorm activity (as indicated by geosynchronous energetic electron injections) the density becomes increasingly variable in these regions. Occasionally, up to order-of-magnitude density variations are observed over several minute timescales corresponding to regions with physical dimensions on the order of 1000 km or less. The appearance of these short-duration, cold-plasma intervals is strongly correlated with energetic ion and electron signatures both at the spacecraft making the plasmaspheric observations and at other spacecraft observing simultaneously in the midnight region. Such energetic particle signatures are indicative of the growth and expansive phase of geomagnetic substorms. We conclude that the appearance of these short-duration, plasmaspheric intervals is due to a reconfiguration of the duskside magnetosphere during geomagnetic substorms.

Introduction

The density structure of the plasmasphere has been studied extensively since the beginning of the Space Age. The early *in situ* studies [*Gringauz*, 1962] and ground-based whistler studies [*Carpenter*, 1963] of the radial extent of the plasmasphere revealed local time asymmetries in both the noon-midnight and dawn-dusk directions. The duskside plasmasphere was shown to be more highly variable in radial extent, and on average to extend further out in L-shell. This region became known as the duskside bulge. Subsequent studies of this region found that the entire plasmasphere, including the bulge region, was larger when Kp was small and vice versa [e.g., *Carpenter et al.*, 1966, 1970]. The local-time of the bulge region moved from post-dusk during quiet times towards noon with increasing levels of geomagnetic activity. *Nishida* [1966] theoretically studied the plasmaspheric bulge region by examining the equipotentials (or flow lines of zero energy particles) in the inner magnetosphere by superposing the corotation electric field with a dawn-dusk convection electric field. The resulting teardrop shaped "plasmapause" with its apex at the stagnation region at 1800 LT has been the first-order paradigm of the plasmapause location ever since. This is despite numerous studies (see *Carpenter et al.*, [1993] for references) that showed the plasmasphere, particularly the duskside bulge, was not well explained by this simple model.

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This paper will briefly present some observations made with an unique suite of low-energy plasma analyzers that are currently fielded on three synchronous orbit spacecraft. This study will also make use of energetic particle measurements obtained by the same satellite, plus four other synchronous spacecraft. The combination of these multiple synchronous spacecraft datasets creates a unique capability to monitor the duskside bulge configuration on a quasi-global scale as a function of changing geomagnetic and substorm conditions. Much of the work that we presented at the 10th Taos workshop on the Earth's Trapped Radiation Environment has been published elsewhere [*McComas et al.*, 1993; *Moldwin et al.*, 1994a,b]. This short paper will briefly summarize some of the results contained in those works and will highlight the main result of the talk (the relationship between the energetic particle flux behavior and the appearance of plasmaspheric plasma at synchronous orbit). A more detailed study of this topic is in preparation for submission to the *Geophysical Research Letters*.

Observations

This study uses data from the magnetospheric plasma analyzers (MPA) that are currently fielded on three synchronous spacecraft (1989-046, 1990-095, and 1991-080). We will only present results from 1989-046 (located at 165°W) and 1990-095 (located between 70° and 102°E). A complete description of the MPA instruments is given by *Bame et al.* [1993]. We also utilize the energetic particle data obtained with the synchronous orbit particle analyzers (SOPA) fielded on the same three satellites. In addition, we use energetic particle measurements from the charged particle analyzers (CPA) located on two other synchronous spacecraft. Details of these instruments are given by *Belian et al.* [1992] and *Higbie et al.* [1978], respectively. Combining MPA and SOPA (or CPA) observations provides measurements of both ions and electrons over the energy range of approximately 1 eV to several MeV.

We use MPA measurements to identify plasmaspheric intervals, which we define as being plasma that is both dense (>10 cm^{-3}) and cold (=1 eV). Figure 1 shows the density and temperature profiles for a plasmaspheric interval observed on April 19, 1993, with spacecraft 1989-046. There is generally an inverse correlation between the number density and the temperature of the low-energy ions; namely, the higher the density, the cooler the temperature. This relationship has been compared to predictions for the ion-cyclotron instability by *Gary et al.* [1994]. We also find that the variability in the density in these plasmaspheric intervals is correlated with increasing geomagnetic activity (as indicated by Kp), and in particular with individual substorm activity [*Moldwin et al.*, 1994b]. This relationship is shown in Figure 2, which plots the parameter *Var* (the point-to-point density variability within an interval) as a function of Kp. The temporal variability in the density can be converted to a spatial scale if we estimate the velocity at which these structures pass the spacecraft. Using typical duskside velocities measured with electric field measurements in the plasmaspheric bulge region (3 km s^{-1} [*Baumjohann et al.* 1985]), these dense plasma regions have lengths <1000 km.

We also find a systematic behavior of the energetic ions and electrons during the short-duration plasmaspheric events. Figure 3 shows the energetic ion and electron fluxes for the same interval shown in Figure 1. The interval of plasmaspheric plasma is indicated by the vertical lines. Plasmaspheric plasma is observed in the flux decline preceding an energetic particle injection. The exit from the plasmasphere occurs ~20 minutes before the injection. The beginning of the dropout of energetic particles at geosynchronous orbit has been interpreted as the beginning of the growth phase of a geomagnetic substorm [e.g., *Baker and McPherron*, 1991] while the simultaneous injection of both ions and electrons in the midnight region signals the onset of a substorm [e.g., *Sauvaud and Winckler*, 1980].

The time of substorm onset is compared to the entry and exit times of the plasmaspheric intervals in Figure 4. Entry (circles) or exit (diamonds) times coincident with the substorm onset would lie on the diagonal line. The plasmaspheric intervals were typically entered approximately an hour prior to substorm onset and were left approximately a half hour after onset. Of these 15 intervals with no more than one onset within ±1 hour of the interval, only one did not have a clear substorm signature. This demonstrates that the short-duration, plasmaspheric intervals are highly correlated with substorm activity. For the 2 events that observed the plasmaspheric interval in the injection region (Figures 1 and 3 show one of these two events), the intervals occurred during the growth phase of the substorm.

Interpretation and Conclusions

We interpret the strong correlation of the short-duration, plasmaspheric intervals with substorm signatures in the energetic particles as signifying that the plasmaspheric regions observed in the outer magnetosphere are brought out beyond synchronous orbit by a reconfiguration of the duskside magnetosphere during the substorm sequence. Thermal ion motion is governed by ExB drift; therefore, an outward motion of a filled plasmaspheric flux tube requires an eastward electric field within the plasmasphere. During the growth phase of a geomagnetic substorm, an eastward induction electric field is generated in the midnight region due to the earthward motion of the plasma sheet/current sheet that "stretches" the dipole field into a more tail-like configuration [e.g., *McPherron*, 1970]. Magnetic field line stretching and the accompanied energetic electron decrease has been systematically observed to extend from the midnight region to noonward of dusk during large substorms [*Nagai*, 1982a,b]. Eastward electric fields have also been deduced from whistler measurements in the duskside bulge region during the substorm sequence [e.g., *Parks*, 1978; *Carpenter et al.*, 1979]. Therefore, the duskside bulge region is apparently populated by detached plasma regions [e.g., *Chappell*, 1974], or plasma tails [e.g., *Maynard and Chen*, 1975], or is characterized by a large-scale, rapid "breathing" of the duskside plasmasphere which is generated by the reconfiguration of the inner magnetosphere during the growth phase of geomagnetic substorms. Density variability within these regions is also imposed by the substorm electric fields.

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Figure 1. The density and temperature of the low-energy (1-120 eV) ions observed with 1989-046 on April 19, 1993. The interval of plasmaspheric plasma extended from ~0940 UT to ~1000 UT..

Figure 2. The relationship of the density variation within the plasmaspheric intervals (as indicated by the parameter *Var* [*Moldwin et al.*, 1994b]) and the level of geomagnetic activity as indicated by Kp.

Figure 3. The energetic electron (E ~50 - 300 keV) and ion (E~50 - 200 keV) behavior during the same interval as shown in Figure 1. The vertical lines designate the time of the plasmaspheric interval.

Figure 4. The entry (circles) and exit (diamonds) times of the short-duration plasmaspheric intervals plotted as a function of the time of substorm onset as determined from energetic electron or ion injections observed at synchronous orbit.

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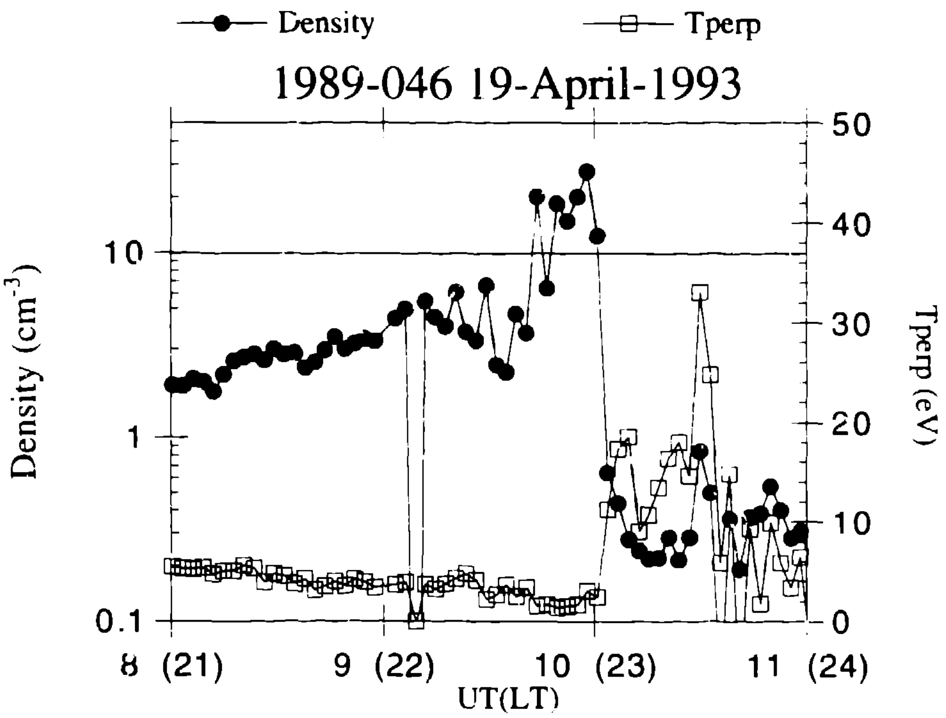
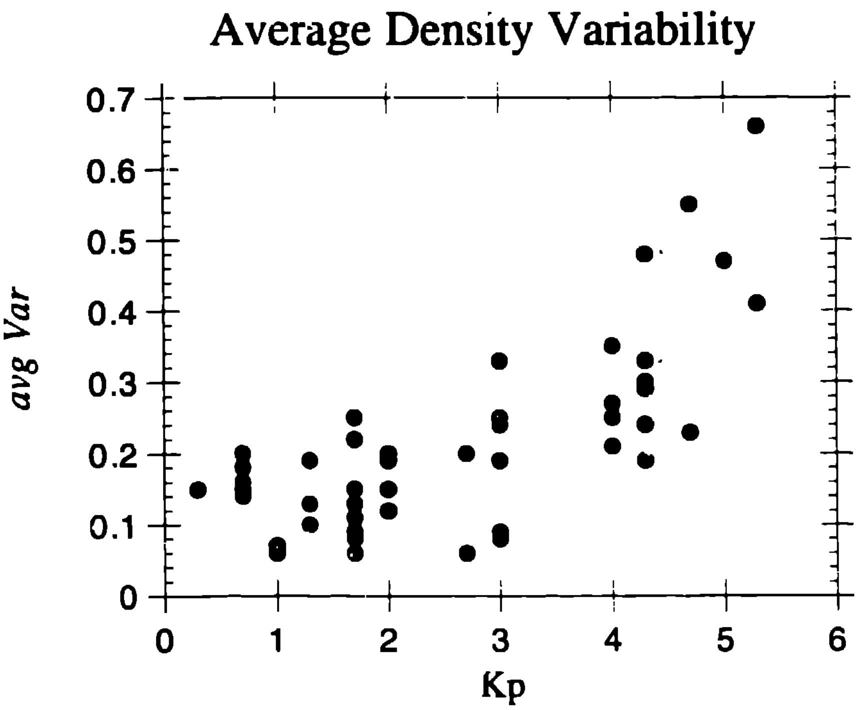
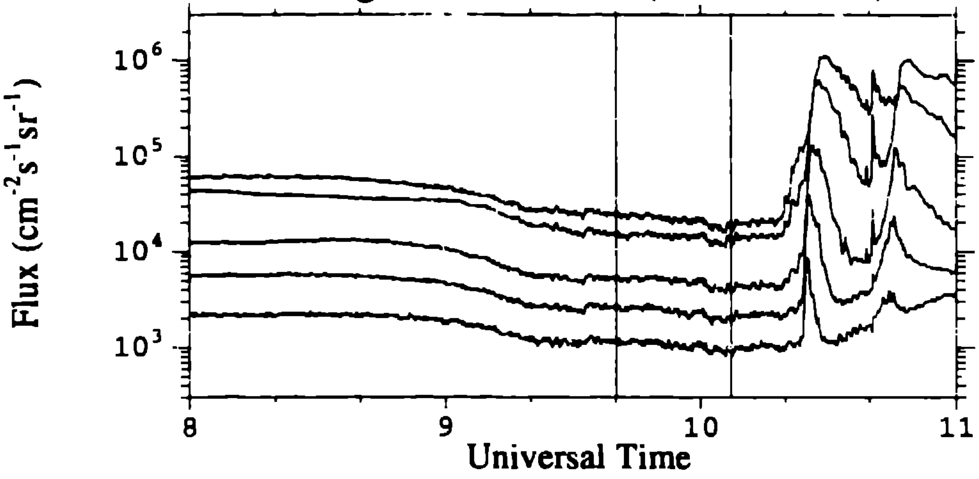


Density
Tperp
1989-046 19-April-1993
Density (cm^{-3})
10
1
0.1
Tperp (eV)
50
40
30
20
10
0
8 (21)
9 (22)
10 (23)
11 (24)
UT(LT)

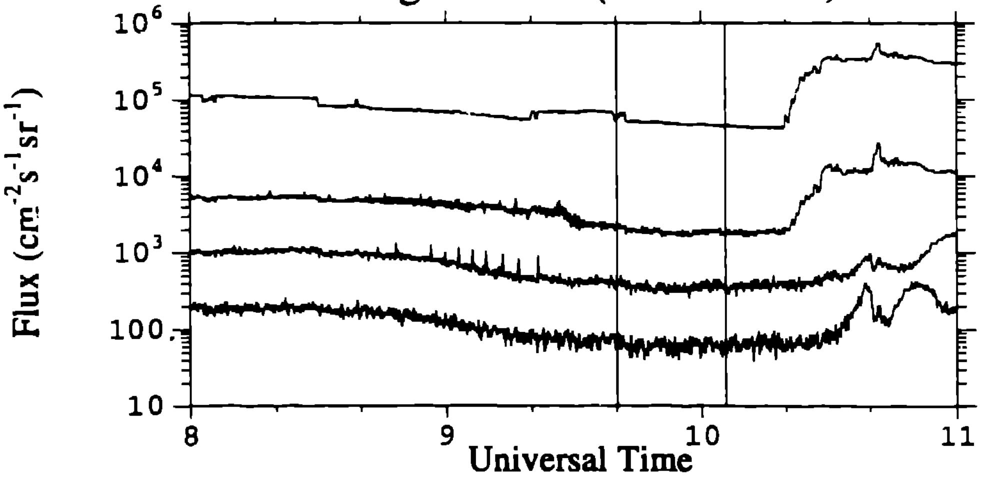


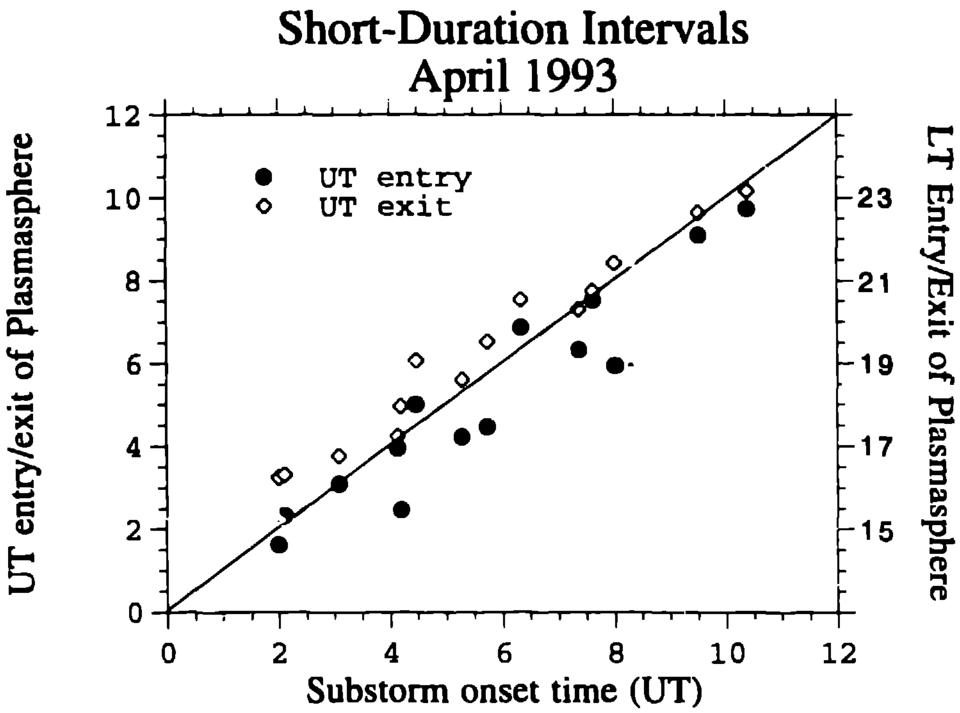
Average Density Variability
avg Var
Kp
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1
2
3
4
5
6

April 19, 1993 1989-046
Energetic Electrons (50-315 keV)



April 19, 1993 1989-046
Energetic Ions (50-250 keV)




Short-Duration Intervals
April 1993
UT entry
UT exit
UT entry/exit of Plasmasphere
LT Entry/Exit of Plasmasphere
Substorm onset time (UT)
0
2
4
6
8
10
12
15
17
19
21
23